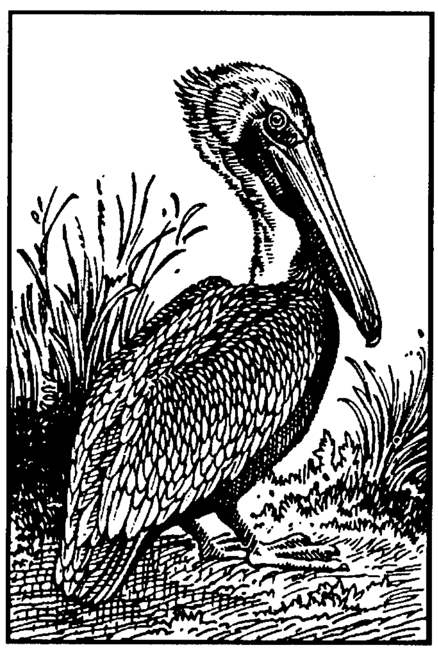
US Army Corps of Engineers
Waterways Experiment Station

Wetlands Research Program Technical Report WRP-DE-14

Wildlife Community Habitat Evaluation: A Model for Deciduous Palustrine Forested Wetlands in Maryland

by Richard L. Schroeder


September 1996 – Final Report

The following two letters used as part of the number designating technical reports of research published under the Wetlands Research Program identify the area under which the report was prepared:

	Task		Task
CP	Critical Processes	RE	Restoration & Establishment
DE	Delineation & Evaluation	SM	Stewardship & Management

Corps of Engineers Research Report Summary, September 1996

Wildlife Habitat Evaluation

Wildlife Community Habitat Evaluation: A Model for Deciduous Palustrine Forested Wetlands in Maryland (TR WRP-DE-14)

ISSUE:

Wildlife habitat models have typically focused on one species. Models are needed to evaluate habitat for wildlife communities and groups of key wildlife species.

RESEARCH OBJECTIVE:

This wetland community model meets the needs of Corps field biologists by providing them with a well documented, straightforward approach to evaluating the habitat functions and values of deciduous palustrine forested wetlands. This information is necessary to aid the Corps in its role under Section 404 of the Clean Water Act to protect existing wetlands or to provide adequate mitigation for unavoidable wetlands losses. The model is structured to allow rapid (general) or time-consuming (more detailed) applications.

SUMMARY:

The model was developed with several levels of detail and can be applied using a Geographic Information System (GIS) approach. The model output is a measure of the expected level of species richness of forest interior birds, reptiles, and amphibians. Model inputs include typical habitat variables such as tree height as well as spatial variables such as permeability of tract boundaries and tract isolation. The test of the model indicated significant positive correlations between the output and interior bird species richness from 18 Breeding Bird Census locations.

AVAILABILITY OF REPORT:

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Wetlands Research Program

Technical Report WRP-DE-14
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Final report

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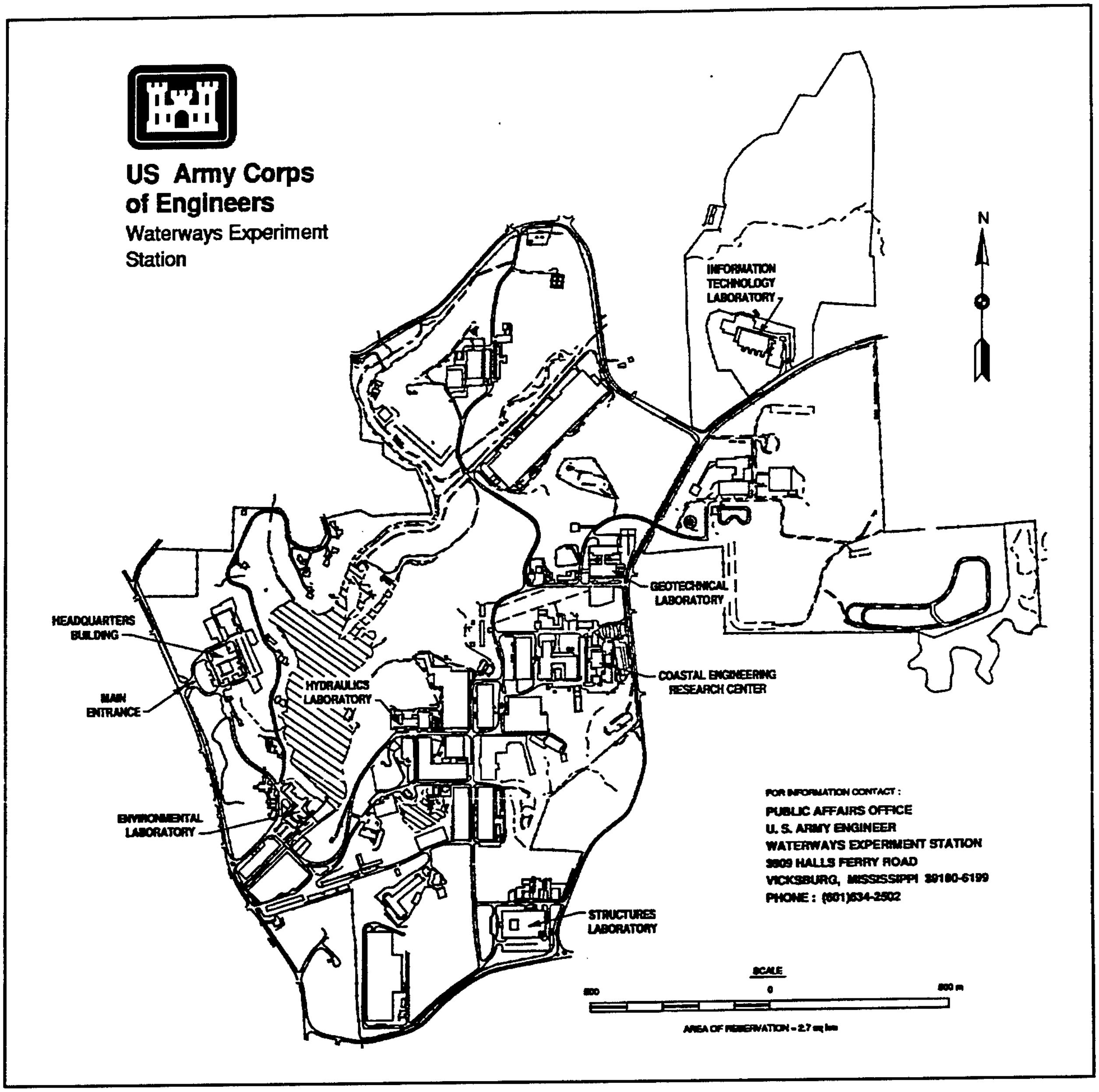

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Preface

The work described in this report was authorized by Headquarters, U.S. Army Corps of Engineers (HQUSACE), as part of the Delineation and Evaluation Task Area of the Wetlands Research Program (WRP). The work was performed under Work Unit 32756, for which Mr. Ellis J. Clairain, Jr., Wetlands Branch, Environmental Laboratory (EL), U.S. Army Engineer Waterways Experiment Station (WES), was Technical Manager. Mr. John Bellinger (CECW-PO) was the WRP Technical Monitor for this work.

Mr. Dave Mathis, Jr. (CERD-C), was the WRP Coordinator at the Directorate of Research and Development, HQUSACE; Mr. William L. Klesch (CECW-PO) served as the WRP Technical Monitor's Representative; Dr. Russell F. Theriot, EL, was the Wetlands Program Manager. Mr. Clairain was the Task Area Manager.

This work was performed by Mr. Richard L. Schroeder, National Biological Service, Midcontinent Ecological Science Center, Fort Collins, Colorado. Mr. R. Daniel Smith, Wetlands Branch, EL, was the Project Manager under the general supervision of Mr. Clairain, Chief, Wetlands Branch, EL; Dr. Conrad Kirby, Chief, Ecological Research Division, EL; Dr. Edwin Theriot, Assistant Director, EL; and Dr. John Keeley, Director, EL.

Ms. M. E. Keller and Mr. C. Robbins assisted in compiling the list of Maryland forest interior birds, and Messrs. K. Buhlmann, S. Gotte, J. Jacobs, J. Mitchell, and R. Reynolds assisted with compiling the list and cover type use of Maryland reptiles and amphibians. Ms. S. L. Haire provided assistance with the compilation of habitat requirements for the reptiles and amphibians and conducted the Geographic Information System applications of the model. Ms. N. Sexton provided assistance with compiling habitat information for forest interior birds. Mr. R. Bruleigh assisted with the requisition of maps and data for the Breeding Bird Census (BBC) plots used to test portions of the model hypotheses. The compilers of the 18 BBC plots are commended for their assistance in identifying the bird census plot locations and providing additional information on plot and habitat conditions.

Individual reviewers assisting with their thoughtful and constructive comments were: Ms. Keller and Messrs. A. W. Allen, R. H. Jones, S. Martin, and R. B. Stiehl.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

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1 Introduction

This document provides habitat information and a model for evaluating the quality of wildlife habitat in deciduous palustrine forested wetlands in Maryland. The primary intended use of the model is to assist biologists involved in evaluating these wetlands, both from an impact assessment and management perspective. The U.S. Army Corps of Engineers and the National Biological Service have a common interest in providing improved tools for community-based wildlife habitat assessment.

The Habitat Model section provides documentation of the logic and pertinent assumptions used to develop the model. The model presents testable hypotheses, based on a comprehensive review of pertinent literature, and use of existing data. The Habitat Use Information section provides a summary of the information used as the foundation for the model. The Model Test section describes the current status of tests of model hypotheses.

2 Habitat Model

Model Output

This model provides a rapid method to evaluate the quality of wildlife habitat in deciduous palustrine forested wetlands. The model does not attempt to evaluate all aspects of the wildlife community, but focuses on two species groups of special concern in the area: (a) forest interior birds, and (b) reptiles and amphibians (see Appendix A). These two groups are of special concern because of their sensitivity to forest fragmentation and changes in wetland hydrology and because of their declining populations.

The output of the model is an index of native richness defined as the combined richness of birds sensitive to fragmentation and reptiles and amphibians. The index is scaled from 0 to 1, where 1.0 represents a deciduous palustrine forested wetland that has the habitat and landscape conditions necessary to support maximum native richness over time. The model is scaled from 0 to 1 to be used with the Habitat Evaluation Procedures (HEP) developed by the U.S. Fish and Wildlife Service (1980).

Model Applicability

The model is intended for application in deciduous palustrine forested wetlands in Maryland. The following description of deciduous palustrine forested wetlands was taken from publications describing wetlands in Delaware and New Jersey (Tiner 1985a, 1985b). Comparable descriptions of wetlands in Maryland were not found.

Red maple (*Acer rubrum*) is a widespread tree in these forested wetlands and is generally dominant in seasonally flooded swamps and very abundant in temporarily flooded areas. Although red maple dominates most of these forested wetlands, specific plant community structure varies between individual wetlands based on soil type, water regime, and historical land use practices.

The model may be suitable for application in other areas of the eastern United States with deciduous palustrine forested wetlands or other structurally similar wetlands. Application in other areas should be conducted only after a thorough review of the model to determine if the assumptions and model structure appear to be reasonable for the habitat and species of concern.

Model Description

Overview

The richness of forest interior birds and reptiles and amphibians in deciduous palustrine forested wetlands is related to the size and shape of the wetland, its internal habitat features, and the landscape context in which it exists. Internal habitat features are referred to as plot-level variables and include measures of vegetative structure, such as tree canopy cover. Landscape features are referred to as tract-level variables and include measures of size, shape, and isolation. Tract and plot definitions are as follows:

a. *Tract.* A contiguous unit of deciduous palustrine forested wetland, including the combined habitat of forested wetlands joined by corridors, bounded by an area > 10 m wide (Lynch and Whigham 1984; Askins, Philbrick, and Sugeno 1987) and consisting of either nondeciduous palustrine forested wetland habitat or a barrier to species movement.

b. *Barrier.* A physical feature that restricts movement at the boundary of a tract. Barriers include roads, rivers, lakes, railroad tracks, and similar large exposed areas.

c. *Plot.* A sampling area within a tract for the purposes of estimating values for internal habitat variables.

Description of tract variables and relations

This section describes the variables and methods that are used to assess the suitability of individual tracts of deciduous palustrine forested wetlands. Documentation of the sources of literature used to develop these variables and hypotheses is provided in the Habitat Use Information section.

The species-area relation forms the basis of the model because the number and types of species that occupy forested wetland tracts are strongly influenced by tract size. A species-area curve was developed from data on minimum tract sizes used by forest interior birds. These data were found for 11 of the 19 interior birds used in this model (Table 1). The formula for the species-area curve to fit these data was developed with the "Nonlin" program from SYSTAT (Wilkerson 1988). The equation to fit this curve (Figure 1) is:

$$Y = 2.227 * A^{0.273}$$

where

Y = bird species richness

A = area in hectares.

Table 1
Minimum Tract Sizes for Forest Interior Birds

Species	Minimum Tract Size, ha	Source
Kentucky warbler	2.3	Blake (1991)
Wood thrush	5.1	Blake (1991)
Scarlet tanager	16.2	Blake (1991)
Worm-eating warbler	23	Askins et al. (1987)
Acadian flycatcher	24	Blake (1991)
Ovenbird	24	Blake (1991)
Louisiana waterthrush	42	Hayden et al. (1985)
Northern parula warbler	54	Hayden et al. (1985)
Cerulean warbler	65	Blake (1991)
American redstart	118	Blake (1991)
Hooded warbler	600	Blake (1991)

Comparable data for all forest interior birds, reptiles, and amphibians occupying deciduous palustrine forested wetlands were not found in the literature. It is assumed that this species-area curve can be used to reflect the changes in native richness in different sizes of forested wetland tracts. In theory, the number of species will continually increase with increases in area. For purposes of this model, however, a maximum size area must be selected to represent the highest output of the model, a suitability index of 1.0. This area is assumed to be 3,000 ha. Using the species-area equation presented above, a 3,000-ha forested wetland tract would yield a prediction of 19.8 forest interior bird species, approximating the 19 species used in this model.

Based on the small home ranges of most reptiles and amphibians, 3,000 ha should be adequate to retain a full complement of these animals. Users of this model should be aware that to support black bears or other large mammalian carnivores, total areas of available (accessible to the animal) and suitable (forested wetlands, upland forest, etc.) habitat would need to be larger than 3,000 ha.

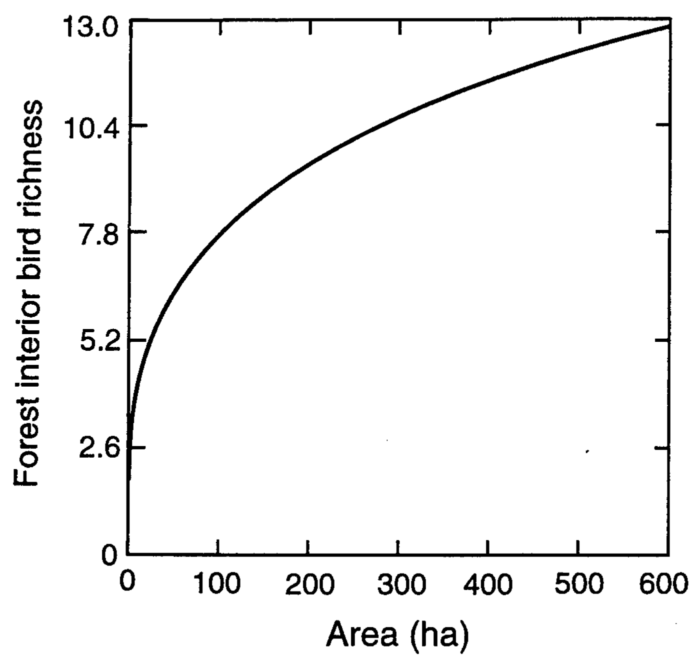

Figure 1. Species-area curve developed from forest interior bird data

Most palustrine forested wetlands in Maryland are much smaller than 3,000 ha (81 percent of individual palustrine forested wetlands are less than 4 ha in size).[1] Thus, most palustrine forested wetlands will score fairly low for this part of the model, reflecting the fact that they are not expected to have high species richness of forest interior birds, reptiles, and amphibians. Regardless of where the maximum size area is set for the model, the output will yield the same relative differences in suitability between two different sized areas. The 3,000-ha standard is chosen because it appears to be biologically reasonable and because it is likely that all of the palustrine forested wetlands in Maryland will fall within this range, allowing effective application of the model without revisions.

The species-area curve alone is insufficient for an evaluation. Habitat fragmentation can modify the effective size of a forest tract as it relates to the ability of the tract to contribute to native richness. An individual forest tract is functionally linked to the habitats that surround it. The area of a tract may be effectively enlarged with permeable boundaries (similar cover types at the tract's perimeter) or an abundance of other nearby forested wetland tracts. Further, tracts with low amounts of interior or core habitat have less effective area for interior species, which are an important component of native

[1] C. E. Keller, personal communication, U.S. Fish and Wildlife Service, Annapolis, MD.

richness. The effective area of a tract is a function of: (a) the actual area; (b) the amount of core area in each tract; and (c) the degree of isolation of each tract, as follows:

$$\textit{Effective tract area} = (\textit{measured area} \times \textit{core area factor} \times \textit{isolation factor})$$

Core area factor (TV1). The definition of core area is:

The area of a tract that is 100 m or more from a tract boundary that is bordered by nonforested habitat.

The percent of a tract in core area is determined by dividing the amount of area 100 m or more from a nonforested tract boundary by the total tract area. Many forested wetlands occur in larger areas of upland forest. A forested wetland entirely surrounded by upland forest can have 100-percent core habitat.

A tract with 0 percent of its area in core habitat (either a very small tract or one that is highly linear or convoluted, and surrounded by nonupland forest) is assumed to support 40 percent fewer species over a long time period on a regional scale. The 40-percent reduction was estimated from an assessment of the 70 species of birds and herps. It is assumed that all 19 forest interior birds are sensitive to fragmentation, and based on comments received from eastern herpetologists, it is assumed that nine of the herps are sensitive (all sensitive species are noted in the list of species in Appendix A).

The amount of core area can be factored into this model by modifying the actual tract area to yield a lower effective area of suitable habitat. The core area factor is computed as follows:

$$0.15 + (0.85 \times \textit{percent core area (decimal form)})$$

The 0.15 constant is necessary to modify tract area in such a manner that predicted species richness levels will be 40 percent lower than predicted using the original total area, for worst-case conditions. The 0.85 constant scales the core area factor to a maximum value of 1.0, as core area approaches 100 percent.

Isolation factor (TV2). The definition of the isolation factor is:

A function of two variables: permeability of the edge of a tract and the amount of deciduous palustrine forested wetland habitat within a 2-km buffer of the tract.

It is assumed that tracts that are highly isolated will support approximately 40 percent less species than those that are not isolated, specifically, those species assumed to be sensitive to fragmentation. For the model to reflect

this, the effective area of tracts that are not isolated should be increased by a factor of 6.5. A factor of 6.5 indicates that a tract is not isolated and is surrounded by similar habitat. When applied in the model, this factor will modify tract area to reflect the 40-percent difference in native richness levels compared to the original tract area predictions. The two measures of isolation used in this model are each scaled from 1.0 to 2.55, so their product yields a value ranging from 1.0 to 6.5.

Edge permeability refers to the ability of the adjacent habitat to be traversed by wildlife species to accommodate dispersal and movement. The permeability factor (Table 2) is determined by assuming that upland deciduous forest represents the most permeable border, and thus should have the highest value. Specific values for the other cover types were determined by relative comparison to percent use of upland forest. Data used to support these hypotheses are presented in the Habitat Use Information section (see Table 3).

Table 2
Permeability Factors for Each Cover Type

Cover Type	Permeability Factor
Deciduous forest	2.55
Coniferous forest	1.97
Shrub	1.89
Palustrine emergent wetland	1.89
Grass/forb	1.60
Lakes/rivers	1.53
Pasture/hay/cropland	1.40
Urban	1.00

Table 3
Percent of Species Using Cover Types Other Than Deciduous Palustrine Forested Wetland

Cover Type						
Deciduous Forest	Coniferous Forest	Shrub	Palustrine Emergent Wetland	Grass/ Forb	Pasture/ Hay/ Cropland	Lakes/ Rivers
100	63	57	57	39	26	34

A single overall permeability factor (ranging from 1 to 2.55) is determined for each forested wetland forest tract by computing the total length of the tract perimeter and the length of perimeter adjacent to each cover type. For

example, assume a tract with a perimeter of 1,000 m had 600 m adjacent to cropland and 400 m adjacent to upland forest. The permeability factor would be computed as a weighted average, as follows:

Cover Type	Perimeter Length	Relative Proportion		Permeability Factor		Weighted Average
Cropland	600 m	0.6	×	1.40	=	0.84
Deciduous Forest	400 m	0.4	×	2.55	=	1.02
		$\Sigma = 1.0$		overall	=	1.86

The second measure of isolation used in the model is the proximity of other deciduous forested wetlands. The assumption is that the effective area of deciduous palustrine forested wetlands should be increased if the tract is within 2 km of other deciduous forested wetland tracts. This factor ranges from 1 to 2.55 and is quantified as follows:

Factor for percent forested wetland habitat within 2 km of tract boundary = 1.0 + (percent deciduous forested wetland within 2 km of tract boundary (decimal form) × 1.55)

The overall isolation factor (a value ranging from 1 to 6.5) used in the model is determined by multiplying the two separate measures:

Isolation factor (TV2) = (permeability factor × percent deciduous forested wetland factor)

It should be noted that although corridors are not treated as a separate tract-level variable, their influence is a component in defining a tract and determining the permeability factor. The definition of a tract includes all contiguous deciduous palustrine forested wetland. A narrow corridor of deciduous palustrine forested wetland habitat connecting two larger forested wetlands would serve to make one contiguous and larger total tract. Thus, the model treats corridors as a part of the tract and their effect in the model is to increase the total area of the tract. I agree with Wilcove, McLellan, and Dobson (1986) that land-use practices which allow populations of target species to exist at least marginally in the surrounding habitat and allow populations to diffuse, as indicated by the permeability factor, are more useful than corridors.

Tract suitability index (TSI)

The tract suitability index (TSI) is derived from a modified species-area curve (Figure 2). The input value (x-axis) is effective tract area and the output (y-axis) is scaled from 0 to 1. Tracts with effective areas ≥3,000 ha receive a TSI of 1.0.

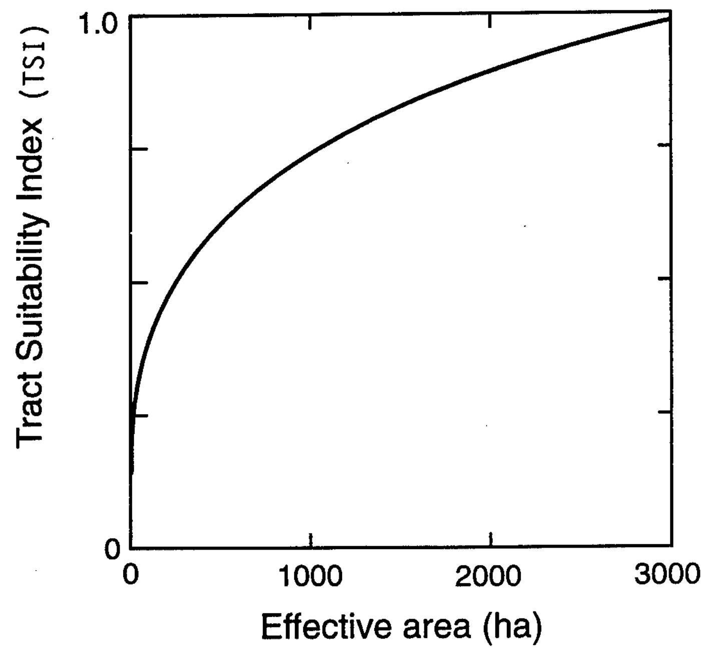

Figure 2. Determination of TSI from effective area (TSI = $(2.227 \times \text{Effective Area}^{0.273})/19.8$)

Description of plot variables (PV) and relations

This section describes the variables and methods that are used to assess the suitability of plot-level habitat of deciduous palustrine forested wetlands. Documentation of the sources of literature used to develop these variables and hypotheses is provided in Chapter 3. The habitat characteristics in each tract strongly influence the level of native species richness. The individual life history of each species of concern dictates the precise habitat features needed for its survival and success. From a community perspective, however, the goal is to describe a general set of conditions that will maximize richness of forest interior birds and herps. It is assumed that maximum native richness will exist in mature forests, with well-developed herb and shrub layers, high levels of soil moisture, and high levels of microhabitat diversity. The specific variables selected to assess these habitat needs are: average tree canopy height, foliage height diversity, soil moisture regime, and microhabitat diversity.

In a study of shelterbelts in Kansas, Schroeder, Cable, and Haire (1992) found that shelterbelts containing forest interior birds had significantly higher values for tree height and foliage height diversity than shelterbelts without interior birds. Forest maturity can be assessed through measures of tree

height. The average height of the tree canopy is readily measured in the field and may be estimated from low-level aerial photographs. Tree height is correlated with tree diameter, and tree diameter is correlated with the availability of cavities (Allen and Corn 1990). It is assumed that tree canopy heights of 20 m or greater are needed for highest native richness, and that richness will decrease linearly as tree heights decline to zero (PV1, Figure 3).

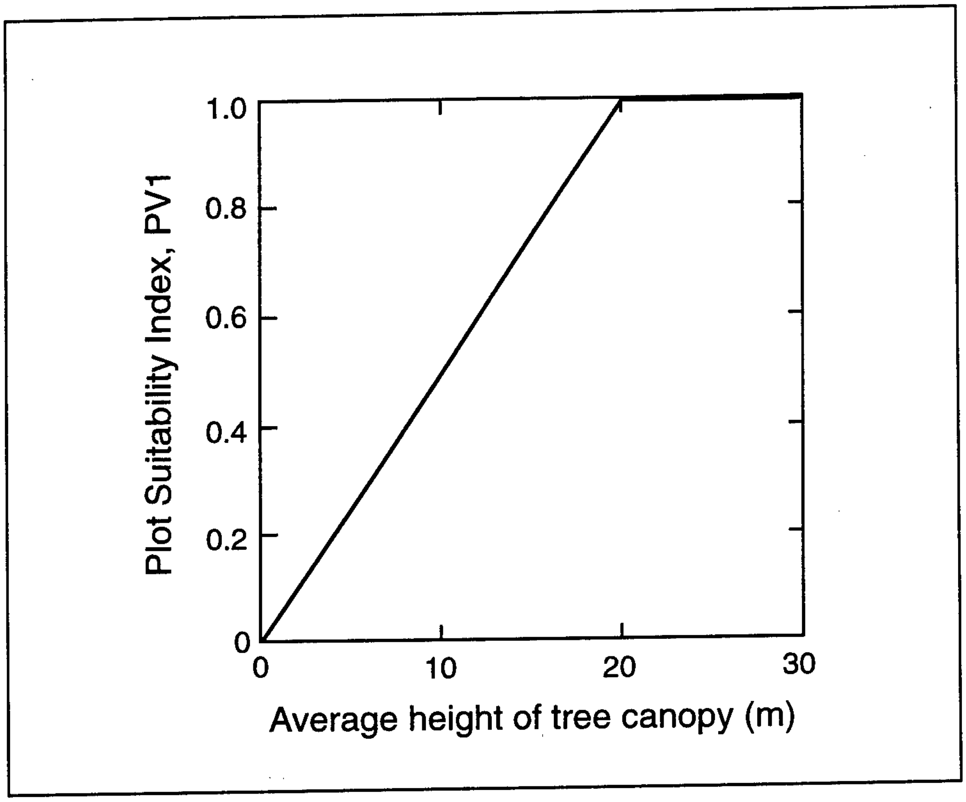

Figure 3. The relationship between the average height of the tree canopy and the suitability index

High levels of foliage height diversity are important to forest interior bird richness (Ambuel and Temple 1983). The literature review of individual reptile and amphibian life histories indicates that habitats with high levels of herbaceous cover and shrubs will support more species than habitats lacking these characteristics. Foliage height diversity is a measure of the distribution of vegetation in the herbaceous, shrub (<5 m), and tree (>5 m) layers, and is highest when there is vegetation in all three layers. It is quantified as follows:

$$\textit{Foliage height diversity (FHD)} = 1/\sum (P_i)^2$$

where

P_i = probability of a "hit" in layer i

It is assumed that habitats with the highest (score of 3) levels of FHD will support the highest native richness and that richness will approach zero as FHD approaches zero (PV2, Figure 4).

The FHD index is a measure of how equally distributed the vegetation is in the three layers, not a direct measure of the absolute amount of vegetation in the layers. The probability *P* is the number of hits in a given layer divided by the number of total hits in all layers combined. The following examples illustrate this measure:

Example 1:

Assume 30 = the total amount of hits in all three layers.

Assume the 30 total hits were equally distributed, 10 hits in each layer. Thus, the FHD would be:

$$FHD = 1/[(10/30)^2 + (10/30)^2 + (10/30)^2] = 1/0.33 = 3$$

Example 2:

Assume 30 = total hits in all three layers, but unevenly distributed, with 5 in the bottom layer, 5 in the middle layer, and 20 in the top layer.

$$FHD = 1/[(5/30)^2 + (5/30)^2 + (5/30)^2] = 1/0.5 = 2$$

Given that the model applies to forested cover, there will often be many hits on vegetation in the top layer. The best habitats occur where the vegetation is equally distributed in all three layers.

Soil moisture is an important determinant of the richness of herpetofaunal assemblages. Based on individual life history information, the 19 forest interior birds used in this model would find suitable habitat in forests with intermediate to wet soil moisture conditions. It is assumed that the highest levels of native richness will be found in areas where the soils are typically seasonally saturated or inundated during the growing season. Native richness is assumed to decrease to moderate levels in areas that are temporarily flooded or saturated, and to be low in areas with soils that are typically dry (PV3, Figure 5).

A diversity of microhabitat features is assumed to be necessary to support the highest levels of native richness. Key microhabitat features include seeps, springs, shorelines, sandy areas, logs, leaf litter, debris, and tree cavities. It is assumed that the best habitats will contain six or more of these microhabitat features, well distributed throughout the entire area (PV4, Figure 6).

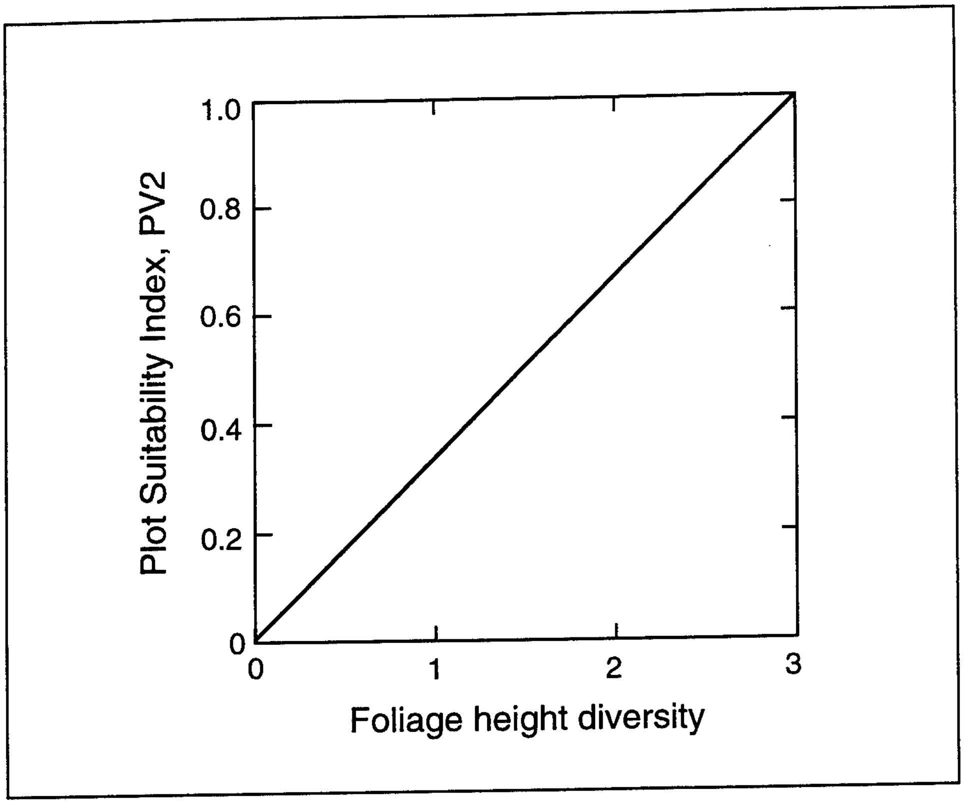

Figure 4. The relationship between foliage height diversity and the suitability index

Plot suitability index (PSI)

The plot suitability index (PSI) is determined with the following formula:

$$PSI = \frac{2(PV1 \times PV2)^{1/2} + PV3 + PV4}{4}$$

Determination of Index of Native Richness

The overall index of native richness is a function of the suitability of the tract, directly modified by the conditions of the plot variables, as follows:

$$Native\ richness\ index = tract\ SI \times plot\ SI$$

Application

Sampling effort may vary because of practical or statistical constraints. Therefore, the level of sampling required to apply the model must be

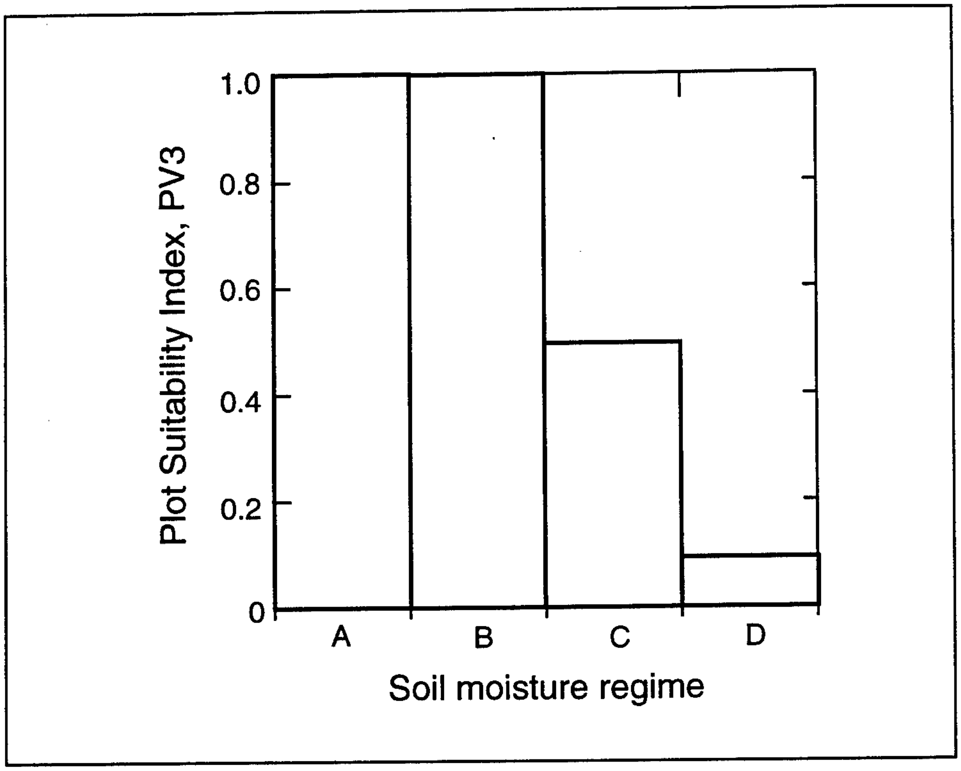

Figure 5. The relationship between the soil moisture regime during the growing season and the suitability index ((A) Seasonally inundated (15 to more than 30 consecutive days); (B) Seasonally saturated (15 to more than 30 consecutive days); (C) Temporarily flooded or saturated (7 to 15 consecutive days); (D) Typically dry (inundated or saturated for less than 7 consecutive days))

determined by each user. The following guidance is provided to assist in applying the model in various situations and at varying intensities.

Applying the model to entire tracts

The basic procedure for applying the model to entire forested wetland tracts is outlined below.

a. Identify and define the boundaries of individual forested wetland tracts and compute the area of each tract.

b. Develop a sampling design to measure the plot-level variables in each tract or in a suitable subsample of tracts stratified by the size categories shown in Table 4. Determine the habitat conditions for each plot-level habitat variable on each selected sampling plot. The actual habitat measurements should be averaged for all plots in the entire tract or subsample of tracts, even though there will likely be variation in some of the habitat measurements across plots. Computation of an SI value for each plot is not recommended because the model is intended to

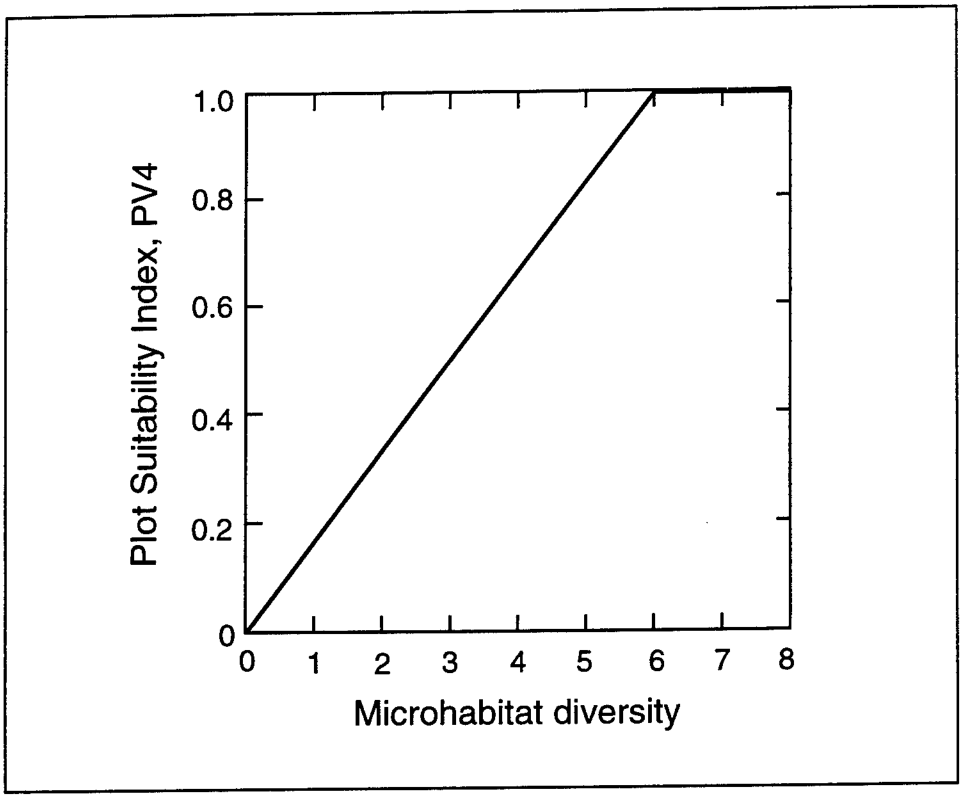

Figure 6. The relationship between the average number of elements of microhabitat diversity per 0.1 ha and the suitability index (Elements of microhabitat diversity include: seeps or springs, shoreline (stream or pond), depression for temporary water, sandy areas, logs, piles of debris or brush, tree cavities, leaf litter over >25 percent of area)

Table 4
Area Categories for Forested Wetland Tracts

Effective Area, ha	Tract SI Value	Documentation
0-16	0-0.29	Blake and Karr (1984) - tracts <16 ha contain virtually no interior birds.
>16-100	0.29-0.45	Blake and Karr (1984) - tracts >16 ha regularly contain interior bird species.
>100-600	0.45-0.69	At 100 ha, Temple (1986) found 87-percent frequency of occurrence of interior bird species.
>600-3,000	0.69-1.0	At 600 ha, Blake and Karr (1984) had 100-percent frequency of occurrence of 12 interior bird species.
>3,000	1.0	Robbins et al. (1989) suggested a minimum of 3,000 ha are needed to retain all breeding forest birds in mid-Atlantic region.

assess average conditions for the wildlife community of the entire tract. Compute a single SI value for each plot-level variable for the entire tract, and combine these into the overall plot SI for each tract or subsample of tracts.

c. Use remotely sensed data to assess the tract-level variables. Classify habitats adjacent to the forested wetland tracts and determine the core area and isolation factors. Determination of the isolation and core area factors may be facilitated through the use of a Geographic Information System (GIS), although measures with such tools as a planimeter and dot-grid overlay would also be appropriate. Determine the effective area of each tract, as follows:

$$\textit{Effective area} = \textit{measured area} \times \textit{core area factor} \times \textit{isolation factor}$$

Enter the effective area into the tract SI graph formula (Figure 2), and determine an SI value.

d. Compute an overall native richness index for each tract by multiplying the tract SI by the average plot SI for that tract.

e. For between-tract comparisons, such as in a HEP application or other management action, assign the tract to a specific size category (Table 4), based on the effective area. Management or mitigation recommendations should not allow tradeoffs such that actions in smaller tract-size categories are allowed to compensate for losses in larger tract-size categories.

Applying the model to portions of a tract

Situations may arise where the model is to be applied to some portion of an entire tract, for example, when a 15-ha corner of a 700-ha tract is to be impacted. The basic procedure to be followed in determining the native richness index is similar to the steps outlined above, with the following differences:

a. Determine the size of the evaluation area, based on the nature and extent of the potential impact. For example, if a road is cut through the corner of a large tract, the evaluation area might be the area of the actual impact, and any necessary buffer for secondary impacts. Compute the plot variable SI's only within the evaluation area within the tract.

b. Computation of Habitat Units (HUs) (area × native richness index) for use in HEP should be based on the size of the evaluation area, not the entire tract.

c. Regardless of the size of the evaluation area, it is recommended that mitigation or tradeoffs between tracts consider the size categories (Table 4) and not allow inappropriate tradeoffs between large and small tracts. Thus, a loss of 15 HUs from an impact to a corner of a 700-ha tract should be mitigated in a tract >600 ha in size.

Simplified applications of the model

Detailed measurements of all plot- and tract-level variables may not be needed for some applications. The size of forested wetland tracts is the most significant determinant of native richness. A reasonable, but very simple, application of the model could consist of rating tracts using the measured area as an input to the effective tract area SI graph. Such an analysis would provide a quick separation of higher versus lower value habitats.

It may be desirable to conduct a rapid evaluation with a GIS for the entire tract portion of the model but without gathering the plot-level field data. A further level of detail could be added by estimating plot-level conditions or assigning general plot-level suitability values based on age classes of forested wetland stands.

Applying the model using geographic information systems (GIS)

Geographic Information Systems (GIS) enable display and analysis of georeferenced data. A GIS database of landcover types can be digitized from existing maps or aerial photos, or interpreted from satellite images. Analysis of variables in this model can be greatly facilitated using a GIS database constructed for an area of interest.

Procedures were developed to compute the tract-level variables in this model using pcArc/Info software (Environmental Systems Research Institute 1989). Automation of the analyses was accomplished using the Prime minicomputer version of Arc/Info, and this program was later converted to run on a Unix workstation. The program allows the user to run analyses on multiple areas very quickly and consistently. Output of the variables is reported to the screen and in an ASCII file for use in spreadsheet and statistical programs. A digital database containing one or more forested wetland polygons of interest and at least 2 km surrounding the areas of interest is required to run the automated analysis. More specific information or assistance in using GIS for a model application can be obtained by contacting the author.

Habitat unit determination

If this model is to be used in a HEP analysis, it will be necessary to compute HUs by multiplying area by the native richness index (HU = area × richness index). Habitat units are to be determined for each of five specific

size categories of forested wetland tracts (Table 4). HUs should be calculated for the total area within each area category, and any tradeoffs among categories for purposes such as mitigation must occur in an equal or larger area category than the HUs of concern. This is basically the same as treating each size category as a separate cover type. In impact assessment applications, this will ensure that losses in larger tracts will only be mitigated with actions in large tracts. Without such a system, it is possible for HU losses in large tracts to be made up by gains in the combined total of HUs from several smaller tracts. Habitat units should not be summed across all tracts because certain species found in larger tracts will not occur in any number of smaller tracts.

Sample data sets

A more complete understanding of the logic and behavior of quantitative models can be obtained through assessment of sample data sets. The following sample data sets are intended to show the effects of the plot and tract variables on the overall native richness index. Verbal descriptions of these hypothetical situations should aid in visualizing the habitat conditions being portrayed.

The relative importance of the tract and plot variables in the model can be assessed by setting one at very low levels of suitability and the other at maximum levels. The following two scenarios demonstrate the effects on the native richness index from these two extreme conditions.

Scenario 1. This data set depicts a very small forested wetland tract that is highly isolated from other tracts and surrounded by croplands. The internal (plot) habitat represents a mature forest with ideal conditions for the plot variables. The factor for percent forested wetland within 2 km is 1.08, and the permeability factor is 1.4, yielding an isolation factor of 1.51. The core factor is 0.15. The original area is 1.0 ha, and the resultant effective area is 0.23 ha. The tract SI is 0.075 and the plot SI is 1.0, resulting in a native richness index of 0.075.

Scenario 2. This data set depicts a very large forested wetland tract that is not isolated and has a large amount of core area. The internal (plot) habitat represents a very young forest, with small trees, low amounts of understory and ground cover, moderate soil moisture conditions, and low levels of microhabitat diversity. The plot SI for such conditions is 0.3. If the tract conditions are a 1.0 SI, the resultant overall native richness index is equal to 0.3.

Based on these two scenarios, the tract portion of the model exerts the greatest influence on the final native richness index. It is not unreasonable to expect to encounter very small tracts that have high values for the plot variables. The small size of the tract alone will cause the native richness index to be very low and approach zero in cases of very small tracts. On the

other hand, very large tracts of bottomland forest will generally have native richness indices >0.3, even with plot variables in their worst-case condition.

The model is most sensitive to changes in the area of the bottomland tract. A change in tract area in smaller size tracts will have the most significant impact on the native richness index. Changes in area of larger tracts have a less significant impact but still more impact than changes in other model variables. Changes in any one plot or tract variable result in relatively small changes in the richness index.

A sample worksheet to determine plot and tract suitability index values and the overall HSI is provided in Table 5.

Table 5
Sample Worksheet for Plot and Tract SI and Overall HSI Determination

Tract Identification												
	Plot Number and Raw Data											
Plot Variables	1	2	3	4	5	6	7	8	9	10	Average	SI
Average height tree canopy, m												PV1 =
Foliage height diversity												PV2 =
Soil moisture regime												PV3 =
Microhabitat diversity												PV4 =

$$Plot\ SI = \frac{2(PV1 \times PV2)^{1/2} + PV3 + PV4}{4}$$

Tract Variables
Tract area, ha =
Core area factor =
Permeability factor =
Percent deciduous forested wetland factor =
Product of permeability factor and percent deciduous forested wetland factor = Isolation factor =
Effective area, ha = tract area × core area factor × isolation factor =

$$Tract\ SI = \frac{2.227 \times (effective\ area)^{0.273}}{19.8}$$

Habitat Suitability Index

$$HSI = Plot\ SI \times Tract\ SI$$

3 Habitat Use Information

General

A wide variety of wildlife species occupy deciduous palustrine forested wetlands in Maryland and surrounding states. This model focuses on two species groups of special concern in this area: (a) reptiles and amphibians, and (b) forest interior birds (Appendix A).

Amphibians and reptiles are a significant and important wildlife component of North American ecosystems and need special consideration in management and conservation decisions (Gibbons 1988). Anuran amphibians are important in resource evaluations because they serve as indicator species that integrate changes in both terrestrial and aquatic portions of their habitat (Beiswenger 1988). Many amphibians require specialized habitats in wetlands and may serve as indicators of the overall health of wetland ecosystems. The importance of amphibians in eastern forest ecosystems is indicated by the fact that salamander biomass at the Hubbard Brook Forest in New Hampshire is about twice that of birds during the breeding season, and about equal to that of small mammals (Burton and Likens 1975). Declines in amphibian populations are of worldwide concern (Wyman 1990; Bishop and Pettit 1992).

Forest interior bird species are important components of forested ecosystems in Maryland (Bushman and Therres 1988), and regionally throughout the eastern United States (Whitcomb et al. 1981). Of the 19 species identified as forest interior birds in Maryland deciduous palustrine forested wetlands, 13 have declining populations over some portion of their range (Table 6).

Area and Configuration

The species richness of forest interior birds is positively correlated with the size of forest tracts (Whitcomb et al. 1981; Askins, Philbrick, and Sugeno 1987; Freemark and Collins 1992). Bird species requiring forest interior habitat occurred in a highly nested distribution in isolated forest tracts of different sizes in Illinois (Blake 1991). Most species that occurred in smaller woodlots also occurred in larger woodlots, whereas the opposite was not true. Small woodlots were dominated by generalist species that breed and forage in

Table 6
Maryland Deciduous Palustrine Forested Wetland Interior Birds With Reported Population Declines

Species	Source
Cooper's hawk	Tate (1986)
Sharp-shinned hawk	Tate (1986)
Acadian flycatcher	Robinson (1992)
Wood thrush	Sauer and Droege (1992)
Worm-eating warbler	Robinson (1992), Sauer and Droege (1992)
Black and white warbler	Butcher et al. (1981), Hill and Hagan (1991)
Northern parula warbler	Hill and Hagan (1991)
Kentucky warbler	Robinson (1992), Sauer and Droege (1992)
Ovenbird	Butcher et al. (1981), Sauer and Droege (1992)
Louisiana waterthrush	Robinson (1992)
American redstart	Hill and Hagan (1991), Sauer and Droege (1992)
Hooded warbler	Butcher et al. (1981)
Scarlet tanager	Butcher et al. (1981)

many different habitats. Larger woodlots contained more species with specialized habitat requirements. The need for large forests to support forest interior birds is also supported by an analysis of bird survey miniroute data conducted by Whitcomb et al. (1981) (Table 7). Wilcove (1988) determined that populations of neotropical migratory birds did not decline in Great Smoky Mountains National Park during the period from 1947-1948 to 1982-1983, when such declines were in evidence throughout many other areas. These data support the hypothesis that large areas are important for the preservation of neotropical migrants. Robbins, Dawson, and Dowell (1989) recommend that forests be ≥3,000 ha to support all of the native breeding forest birds in the mid-Atlantic region.

The configuration of forest fragments is important in determining the abundance and productivity of forest interior birds. Temple (1986) found that interior bird species were more abundant in habitats with larger amounts of core area (core habitat defined as being >100 m from nonforest habitat). It is recommended that riparian corridor width in Delaware and Maryland be at least 100 m wide to provide habitat for forest interior birds (Keller, Robbins, and Hatfield 1993). The impacts of predation, competition, and nest parasitism by brown-headed cowbirds (*Molothrus ater*) are greater near edges (Temple and Cary 1988). Analyses of the life history patterns of declining songbirds supported the hypothesis that nest predation and parasitism are primarily responsible for recent population declines (Böhning-Gaese, Taper, and

Table 7
Occurrence of Forest Interior Birds in Relation to Extensive Forests (from Whitcomb et al. 1981)

Species	Number of Points Recorded from Sites With Extensive Forest	Number of Points Recorded in all Other Habitats	Sign., P
Black and white warbler	14	0	0.001
Prothonotary warbler	4	0	0.01
Northern parula warbler	25	2	0.001
Ovenbird	30	3	0.001
Louisiana waterthrush	5	0	0.01
Kentucky warbler	14	2	0.001
Hooded warbler	12	1	0.001
American redstart	13	0	0.001

Brown 1993). Robinson (1992) found very high rates (75 percent) of parasitism by brown-headed cowbirds on the nests of neotropical migratory birds in Illinois forest fragments. Only one young was fledged from 15 wood thrush nests. Robinson concluded that these small, isolated woodlots function as population sinks and may be receiving immigrants from source populations from as far as 200 km.

Several studies have estimated minimum areas needed by forest birds (Galli, Leck, and Forman 1976; Robbins 1979; Hayden, Faaborg, and Clawson 1985). Patches larger than estimated minimum areas may be needed to support viable populations of certain bird species (Gibbs and Faaborg 1990). Increasing the effective size of forest areas is necessary to counter the negative side effects of forest insularization (Lynch 1987). This can be accomplished by: (a) increasing contiguous size, (b) promoting compatible land uses in adjacent lands, and (c) increasing the amount of forest area within the region.

Pague and Mitchell (1991) recommend that efforts to conserve the reptile and amphibian community in Back Bay, Virginia, should focus on the protection and restoration of wetlands in large areas.

Isolation

Whitcomb et al. (1981) found that decreasing forest isolation was positively correlated with species richness of forest interior birds. Extensive deforestation in areas surrounding a forest tract may cause populations of forest interior birds to decline and result in their local extinction (Askins and Philbrick

1987). Robbins, Dawson, and Dowell (1989) noted the "proximity to other forests appears to enhance the effective area of a forest for some area-sensitive species." For example, the abundance of long distance migratory forest birds was positively related to the abundance of regional forest area (defined as the total area of forest within 2 km of the center of a forest tract).

From 1953 to 1976, six of ten forest interior bird species declined, while none increased or colonized, in a 23-ha Connecticut nature reserve (Butcher et al. 1981). Extensive urban and suburban development occurred in the immediate vicinity (2-km buffer) of the reserve, increasing the isolation of the site from similar habitat, reducing the buffer of low-density human use, and increasing disturbance from construction, noise, pets, and other human-related activities.

Boundary permeability has been defined as the degree to which the boundary of a habitat patch deflects the movements of a species (Wiens, Crawford, and Gosz 1985). The degree of permeability is a function of characteristics of the species and the boundary itself. The effect of the boundary on an animal depends on features of the patch such as habitat structure, resource levels, and the presence or absence of predators or competitors. In a study of insect movement patterns, Stamps, Buechner, and Krishnan (1987) found that hard edges (totally unsuitable adjacent habitat) inhibited dispersal, whereas even modest increases in edge permeability dramatically increased emigration rates. Land-use practices in adjacent lands that allow at least marginal existence of target species, and thus dispersal between tracts, are thought to be more valuable than corridors (Wilcove, McLellan, and Dobson 1986). Bird species occupying forest patches in Illinois expanded their territories into adjacent old-field or second-growth areas (Blake and Karr 1987). Forest fragments surrounded by urban development had lower forest interior bird richness than fragments surrounded by agricultural land (Whitcomb et al. 1981).

Roads, railways, and canals produce a variety of biotic and abiotic discontinuities that create barriers to animal movements (Mader 1984). Specific effects of roads are: (a) changes in microclimatic conditions; (b) emissions and disturbance, such as noise, headlights, and dust; (c) herbicide spraying and mowing; (d) intensified competition along the edge; and (e) traffic or hunting mortality. Lynch and Whigham (1984) and Askins, Philbrick, and Sugeno (1987) used a 10-m width to define separate tracts in their bird habitat studies, whereas Robbins, Dawson, and Dowell (1989) used 100 m. Any such delineation is somewhat arbitrary (Lynch and Whigham 1984).

Species richness of herpetofaunal assemblages decreases with increasing insularity (Heatwole 1982). Isolation of wetlands, without upland buffers and corridors, may result in higher mortality for younger age classes of amphibians and reduce recruitment and gene flow (Buhlmann, Mitchell, and Payne 1992). Management and protection of wetland wildlife requires the protection of the surrounding terrestrial habitat.

Laan and Verboom (1990) studied the effects of pool size and isolation on amphibian communities in the Netherlands. They found that the probability of species' occurrence in patches with suitable habitat increased with the proximity of a source population and increasing connectivity of the landscape. The presence of wooded areas appeared to be the most important element in increasing landscape connectivity.

Species use of cover types other than forested wetlands can be used as an indicator of their ability to disperse through various surrounding landscapes. Table 3 provides a summary of cover type use by the 70 bird and herp species considered in this model. All of the herps and interior birds would make use of deciduous forest habitat, and thus, would not find such habitat to be a barrier to dispersal. Agricultural lands would pose a barrier to most species and only 26 percent of the species are considered to be able to use agricultural lands.

Vegetation Structure

Bushman and Therres (1988) provided a comprehensive review of the literature on forest interior bird habitat requirements, and additional literature was surveyed. Based on these reviews, a summary of the basic habitat needs of the 19 forest interior birds in Maryland was compiled. The majority of these birds would find suitable habitat in a closed canopy, mature forest, with a mix of dense and open understory conditions. Special habitat needs include the presence of snags, proximity to water, and areas with little or no human disturbance.

Lynch and Whigham (1984) summarized the habitat requirements of 15 neotropical migratory birds (9 of which are included in the list of interior birds used in this model). They noted that these birds tended to be more abundant in mature forests with high plant species richness, tall canopies, and well-developed herb and shrub layers. Foliage height diversity (along with area) was a positive factor in a multiple regression predicting the density of uncommon long distance migratory birds in Wisconsin (Ambuel and Temple 1983).

Species richness of herpetofaunal assemblages can be expected to decrease with decreasing availability of moisture (Heatwole 1982). Species richness of metamorphosing juvenile amphibians was positively correlated with hydroperiod in three South Carolina wetlands (Pechmann et al. 1989). Blymyer and McGinnes (1977) studied the effects on amphibians of clearcuts in Virginia forests. They found 7 species and 82 individuals in uncut forests, no amphibians in 6- to 7-year-old clearcuts, and three species and seven individuals in a 2-year-old clearcut. They note that the abiotic factors of low upper soil moisture and higher temperatures in the clearcuts were the likely causes of the lower numbers of amphibians. Removal of ground cover and underbrush, associated with land clearing, affects all terrestrial species, but is particularly severe for salamanders and certain snakes (Minton 1968). Modification of

aquatic habitats by draining, dredging, pollution, or vegetation removal has serious negative effects on most amphibians. To benefit reptile and amphibian populations, Jones (1988) recommended maintaining or enhancing surface litter and vegetation structure, because they help to moderate temperatures, increase moisture, and provide food and cover.

Based on a literature review of the 51 species of reptiles and amphibians noted to use deciduous palustrine forested wetlands, key habitat features needed to support high numbers of herpetofauna were summarized. The majority of reptiles and amphibians would find suitable habitat in forested wetlands with high amounts of soil moisture, as well as herbaceous and other ground cover and underbrush. The presence of a diversity of microhabitats would be highly desirable. Key features include seeps, springs, shorelines, sandy areas, logs, leaf litter, debris, and tree cavities.

4 Test of Tract Hypotheses

Literature covering a wide geographic area was used to develop the model hypotheses related to interior birds. The sensitivity of forest interior bird richness to area, core habitat, and isolation appears to apply across their range in the eastern deciduous forest, including forested wetlands. Therefore, a study of the relation of the tract variables to the richness of forest interior birds in 18 Breeding Bird Census (BBC) plots in eastern deciduous forests was initiated to provide an independent test of several important model hypotheses. The BBC plots included both upland and wetland deciduous forest types and were mostly in states along the eastern seaboard, from South Carolina to Rhode Island.

An Index of Avian Integrity (IAI) was used as the dependent variable in this test and was defined as the proportion of forest interior birds occurring on a BBC plot compared to the number expected. The expected number was determined from the geographic distribution of the forest interior birds, as indicated in the American Ornithological Union checklist (American Ornithological Union 1983). Only birds listed in Appendix A were included in the analysis. Landscape data for the 18 BBC plots were obtained by working with the plot compilers to identify the plot location on a topographic map. Aerial photographs of these areas were acquired and the forest tract and surrounding 2.5-km buffer were photointerpreted and digitized. Spatial analyses of the model tract variables were conducted using an automated program written for the Arc/Info GIS software.

The IAI was significantly correlated with both the core area factor (TV1) ($r = 0.498$, $P = 0.035$) and the isolation factor (TV2) ($r = 0.572$, $P = 0.013$). Regression of the IAI on the TSI yielded a highly significant ($R^2 = 0.503$, $P = 0.001$) result:

$$IAI = 0.097 + 0.516\ (TSI)$$

This initial test of tract-level hypotheses corroborates the relation between forest interior bird richness and the tract portion of the model. Additional tests are needed to analyze the plot variables and to assess the relationship between model variables and the richness of reptiles and amphibians.

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Appendix A

Table A1
Forest Interior Birds, Reptiles, and Amphibians Occurring in Deciduous Palustrine Forested Wetlands in Maryland

Common Name	Scientific Name
Forest Interior Birds[1]	
Cooper's hawk	*Accipiter cooperii*
Sharp-shinned hawk	*Accipiter striatus*
Broad-winged hawk	*Buteo platypterus*
Barred owl	*Strix varia*
Pileated woodpecker	*Dryocopus pileatus*
Hairy woodpecker	*Picoides villosus*
Acadian flycatcher	*Empidonax virescens*
Wood thrush	*Hylocichla mustelina*
Cerulean warbler	*Dendroica cerulea*
Worm-eating warbler	*Helmitheros vermivorus*
Black-and-white warbler	*Mniotilta varia*
Prothonotary warbler	*Protonotaria citrea*
Northern parula warbler	*Parula americana*
Kentucky warbler	*Oporornis formosus*
Ovenbird	*Seiurus aurocapillus*
Louisiana waterthrush	*Seiurus motacilla*
American redstart	*Setophaga ruticilla*
Hooded warbler	*Wilsonia citrina*
Scarlet tanager	*Piranga olivacea*

(Sheet 1 of 3)

Note: All forest interior birds and those reptiles and amphibians marked with an asterisk are considered to be sensitive to habitat fragmentation.
[1] From Butcher et al. (1981), Whitcomb et al. (1981), Hamel et al. (1982), Blake and Karr (1984), Hayden, Faaborg, and Clawson (1985), and Small and Hunter (1989), with review comments provided by C. Robbins and M. E. Keller.
[2] From Harris (1975) and Behler and King (1979), with review comments provided by K. Buhlmann, S. Gotte, J. Jacobs, J. Mitchell, and R. Reynolds.

Table A1 (Continued)

Common Name	Scientific Name
Reptiles and Amphibians[2]	
Spotted salamander*	*Ambystoma maculatum*
Marbled salamander*	*Ambystoma opacum*
Northern dusky salamander	*Desmognathus fuscus fuscus*
Northern two-lined salamander	*Eurycea bislineata bislineata*
Long-tailed salamander	*Eurycea longicauda longicauda*
Four-toed salamander*	*Hemidactylium scutatum*
Red-spotted newt	*Notophthalmus viridescens viridescens*
Red-backed salamander	*Plethodon cinereus cinereus*
Eastern mud salamander*	*Pseudotriton montanus montanus*
Northern red salamander	*Pseudotriton ruber ruber*
Jefferson's salamander*	*Ambystoma jeffersonianum*
Tiger salamander*	*Ambystoma tigrinum*
Slimy salamander	*Plethodon glutinosus*
Northern spring peeper	*Hyla crucifer crucifer*
Upland chorus frog	*Pseudacris triseriata feriarum*
Bullfrog	*Rana catesbeiana*
Green frog	*Rana clamitans melanota*
Pickerel frog	*Rana palustris*
Wood frog	*Rana sylvatica sylvatica*
Southern leopard frog	*Rana utricularia utricularia*
Northern cricket frog	*Acris crepitans*
American toad	*Bufo americanus*
Fowler's toad	*Bufo woodhousii fowleri*
Cope's gray treefrog	*Hyla chrysoscelis*
Green treefrog	*Hyla cineria*
Gray treefrog	*Hyla versicolor*
Striped chorus frog	*Pseudacris triseriata*
Carpenter frog*	*Rana virgatipes*
Common snapping turtle	*Chelydra serpentina serpentina*
Eastern painted turtle	*Chrysemys picta picta*
Spotted turtle*	*Clemmys guttata*
Eastern mud turtle	*Kinosternon subrubrum subrubrum*
Eastern box turtle	*Terrapene carolina carolina*
Wood turtle*	*Clemmys insculpta*
Five-lined skink	*Eumeces fasciatus*

(Sheet 2 of 3)

Table A1 (Concluded)	
Common Name	**Scientific Name**
Reptiles and Amphibians[2]	
Southeastern five-lined skink	*Eumeces inexpectatus*
Ground skink	*Scincella lateralis*
Black rat snake	*Elaphe obsoleta obsoleta*
Eastern kingsnake	*Lampropeltis getulus getulus*
Coastal plain milk snake	*Lampropeltis triangulum temporalis*
Northern water snake	*Nerodia sipedon sipedon*
Rough green snake	*Opheodrys aestivus*
Northern brown snake	*Storeria dekayi dekayi*
Eastern ribbon snake	*Thamnophis sauritus sauritus*
Eastern garter snake	*Thamnophis sirtalis sirtalis*
Copperhead	*Agkistrodon contortrix*
Worm snake	*Carphophis amoenus*
Racer	*Coluber constrictor*
Corn snake	*Elaphe guttata*
Queen snake	*Regina septemvittata*
Red-bellied snake	*Storeria occipitomaculata*
	(Sheet 3 of 3)

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The species richness of forest interior birds, reptiles, and amphibians in deciduous palustrine forested wetlands is influenced by habitat conditions within the forest and the spatial arrangement of forest tracts within the surrounding landscape. Habitat fragmentation is a major determinant of species richness and composition in these forests. The model predicts richness from an evaluation of habitat and spatial variables, with the highest levels of richness assumed to be found in mature, unfragmented forested wetland tracts. The spatial variables in the model can be assessed with remotely sensed data and analyzed with geographic information systems software. A test of the tract portion of the model revealed positive correlations between the spatial model variables and forest interior bird richness from 18 eastern forest Breeding Bird Census plots.

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